GEOCENTER VARIATIONS CAUSED BY MASS REDISTRIBUTION OF SURFACE GEOPHYSICAL PROCESSES

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Abstract: Both surface and internal mass redistribution causes geocenter variations. The global surface mass redistribution can be measured or modeled and is considered as the primary contributor to the geocenter variations on seasonal time scale. Once the geocenter variations from satellite measurements and from the surface mass load contributors are determined with sufficient accuracy, the residuals between the two will provide important constraints on the mass redistribution from various internal processes. Our results [*Dong et al.*, 1997] suggest that on the time scale from 30 days to 10 years the primary variability of geocenter variations from atmosphere, ocean and surface ground water occurs on the annual and semiannual scales. The lumped sum of these surface mass load induced geocenter variations is within 1 cm level. Preliminary comparison between our geophysical model predicted and satellite (SLR, GPS) measured geocenter variations shows fairly good agreement for annual component; however, not for semiannual component.

1. SUMMARY OF OUR PREVIOUS WORK

We define the geocenter as the center of figure (CF) of the Earth relative to the center of mass (CM) of the Earth including mass load [*Dong et al.*, 1997]. If the origin of our terrestrial reference frame is defined by a set of tracking stations with sufficient global coverage, the variations of the network center will be a good representation of the geocenter variations. Theoretically the spectrum of the geocenter variations is as rich as the sum of spectra from various geophysical processes which are capable of causing mass redistribution. The relation between the geocenter position vector $\mathbf{r}_{CF}$ (defined in CM frame) and the geophysical process induced surface mass load position vector $\mathbf{r}_{CF}$ (defined in the Earth-fixed reference frame) is

$$\mathbf{r}_{CF} = -(1-\frac{h_1+2l_1}{3})\frac{M_l}{M_e+M_l}\bar{\mathbf{r}}_{load} \tag{1}$$

where M_e and M_l represent the mass of Earth (without load) and mass of load respectively, h_1 = -0.290 and l_1 = 0.113 [*Farrell* ,1972], indicating that the deformation slightly enlarges the amplitude of $\mathbf{r}_{CF}$ by about 2.1%. Recent discussion about the relation between the degree one mass load Love number and the reference frame was provided by Grafarend [1997].

Geocenter variations caused by atmosphere, ocean and surface ground water were calculated. On the time scale from 30 days to 10 years, the primarily variability of the geocenter variations from these contributors occurs on the annual and semiannual scales. A sign error in the z-component of the groundwater inferred geocenter variation series of *Dong et al.* [1997] is corrected here. Also, the time tags of the groundwater inferred geocenter variation series should use the middle epochs of each month instead of the first day of the month to better represent the monthly mean time series; this modification affects the phases of all groundwater components. The revised Table 1 and Figure 4 of *Dong et al.* [1997] are given here as Table 1 and Figure 1, indicating that ground water is the largest contributor to all three components at the annual period and both x and y components at the semiannual period. The atmosphere is the largest contributor for the semiannual z component with ground water being about 10% less. Unfortunately, the mass redistribution of the surface ground water is the least understood contributor and deserves substantial further study. The total annual terms are considerably larger than the corresponding semiannual terms by a factor of 6.7, 7.6, 2.7 for x, y, z components respectively (see Table 1). The x, y components of geocenter variations from seasonal to interannual time scales are likely within 1 cm level unless these time series have significant errors, we omitted some important surface mass load contributors, or the internal mass redistribution processes play a dominant role.

Table 1. Annual and Semiannual Geocenter Variations from Surface Mass Redistributions

source*		Annual		Semiannual	
		Amp$^+$. (mm)	Phase$^+$ (deg.)	Amp$^+$. (mm)	Phase$^+$ (deg.)
Atmosphere	x	0.55	284.1	0.23	270.4
	y	1.31	270.7	0.38	36.8
	z	0.87	312.8	0.73	90.7
Ocean non-tidal	x	1.05	258.8	0.39	67.7
	y	0.09	301.0	0.29	101.9
	z	0.18	37.7	0.16	220.6
Ocean tide	x	0.03	87.6	0.21	290.8
	y	0.003	267.6	0.02	110.8
	z	0.03	267.6	0.21	110.8
Ground water	x	3.28	204.8	0.84	139.4
	y	2.94	4.6	0.94	228.2
	z	3.57	220.2	0.66	163.,6

* ECMWF data are used for atmosphere. Isopycnal ocean circulation model is used for ocean non-tidal. Self-consistent equilibrium Sa and Ssa tide models are used for ocean tide.

$^+$ Amplitude A and phase ϕ are defined by $A\sin[\omega(t-t_0)+\phi]$ where t_0 is January 1, 1990, ω is the frequency.

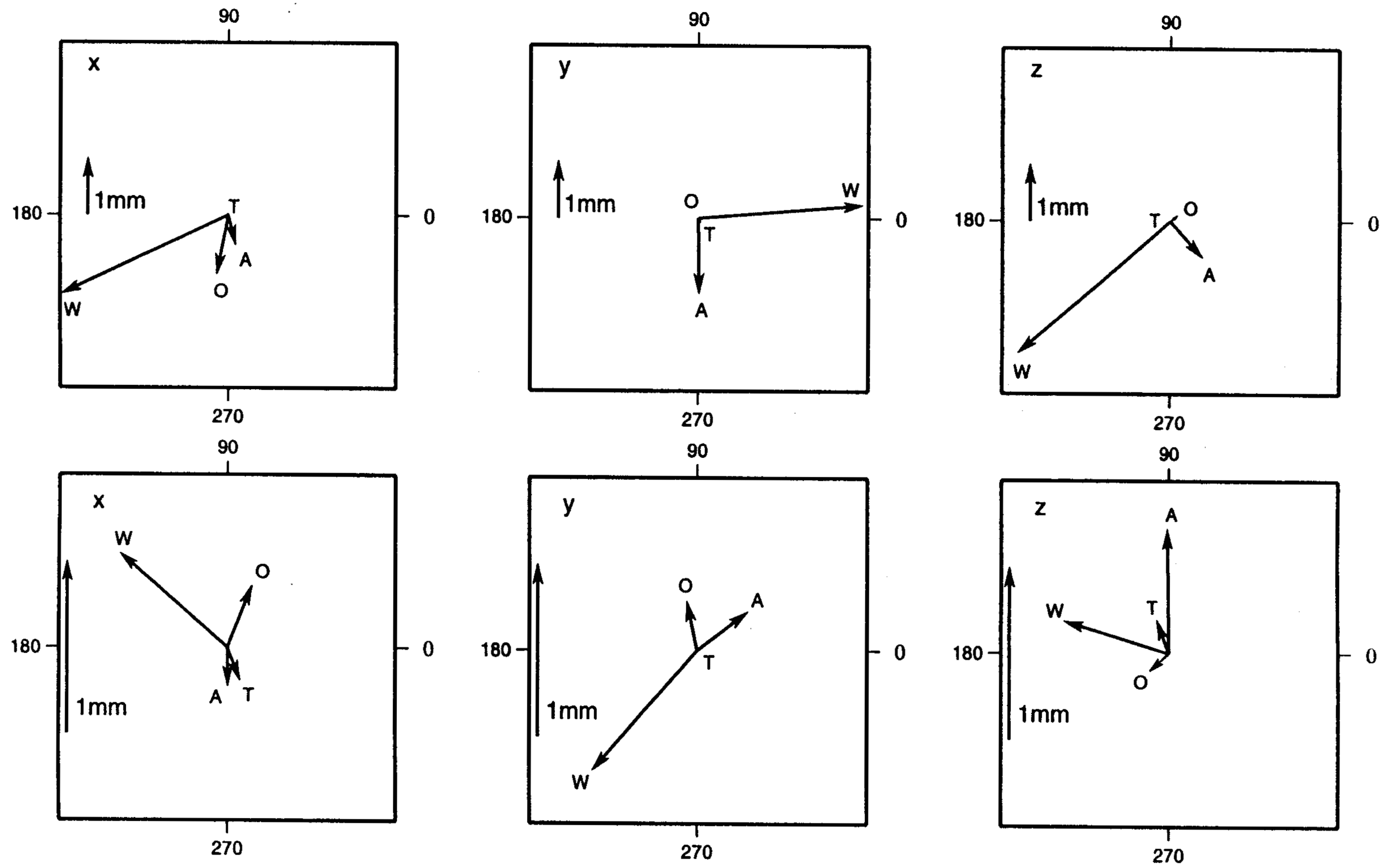

Figure 1: Annual (first row) and semiannual (second row) components of geocenter variation. The notations are: A atmosphere, O ocean current, T ocean tide, W surface ground water. The phase is refered to Jan. 1 with sine convention.

One missing contributor in our previous work is the mass redistribution due to the ice sheet volume and snow cover variations over the land due to lack of data with sufficient resolution on seasonal time scales [*Trupin et al.*, 1992]. The RAND data set of the global snow depth [*Schutz and Bregman*, 1988] infers 2.2 mm annual geocenter variation in z component due to the snow redistribution in the polar region. Satellite-borne radar altimeter data provide another tool to measure the mass variation of the ice sheet. Such a data can reveal seasonal scale variations of the ice sheet volume if the orbital errors can be eliminated effectively [*Yi et al.*, 1997]. For a diagnostic test, we consider a simple case: 10 cm averaged seasonal surface height variation in Greenland and 5 cm averaged seasonal surface height variation in Antarctica. Assuming the density of the compact snow is 400 kg/m^3, the inferred amplitudes of the seasonal geocenter variations for x, y, z are 0.072, 0.063, 0.328 mm for Greenland and 0.023, 0.067, 1.022 mm for Antarctica. This indicates the primary contribution of this source is to the z component and likely less than 1 cm level.

2. COMPARISON WITH SATELLITE DETERMINED GEOCENTER VARIATIONS

Current space-geodesy techniques have captured signals of the geocenter variations from diurnal and semidiurnal bands [*Watkins and Eanes*, 1997] to seasonal or even longer period [*Kar*, 1997]. Special attention should be paid to the measurement of the secular geocenter variation. Since a considerable portion of the secular geocenter variation has been absorbed by the terrestrial velocity reference frame, directly measured secular motion of the global network center will represent the unmodeled part of the secular geocenter motion. Our study is focused on the seasonal time scales. To compare with the geophysical processes inferred geocenter variations on seasonal scales, we choose satellite determined seasonal variations of geocenter from three independent sources: the solution from the combination of LAGEOS I and LAGEOS II SLR data [*Eanes et al.*, 1998], the solution from Topex SLR data [*Cheng*, 1998], and the solution from GPS data [*Zhu et al.*, 1998]. The details of the satellite determined solutions can be found in the corresponding papers (in this report issue). Since the satellite determined solution adopt the definition of CM relative to CF as the geocenter position, we change the sign of these solutions to make the solutions consistent with our definition.

The comparisons of the annual and semiannual components are shown in Figure 2 and Figure 3 respectively. Since the GPS solutions used here are a factor of two larger than the other solutions, we scale the GPS solutions by 0.5 in order to use a common scale in the Figures. For the annual x component, all the three satellite derived solutions show strong agreement in phase with our solution, with the maximum phase difference being within 12 degrees. The GPS solution has the similar amplitude as our modeled solution, while the SLR solutions have only half of the predicted amplitude. For the annual y component, the SLR solutions have the similar amplitude as the modeled solution, where the GPS solution is a factor of two too larger. The phase differences are within 50 degrees of each other; in particular, the solution of *Eanes*

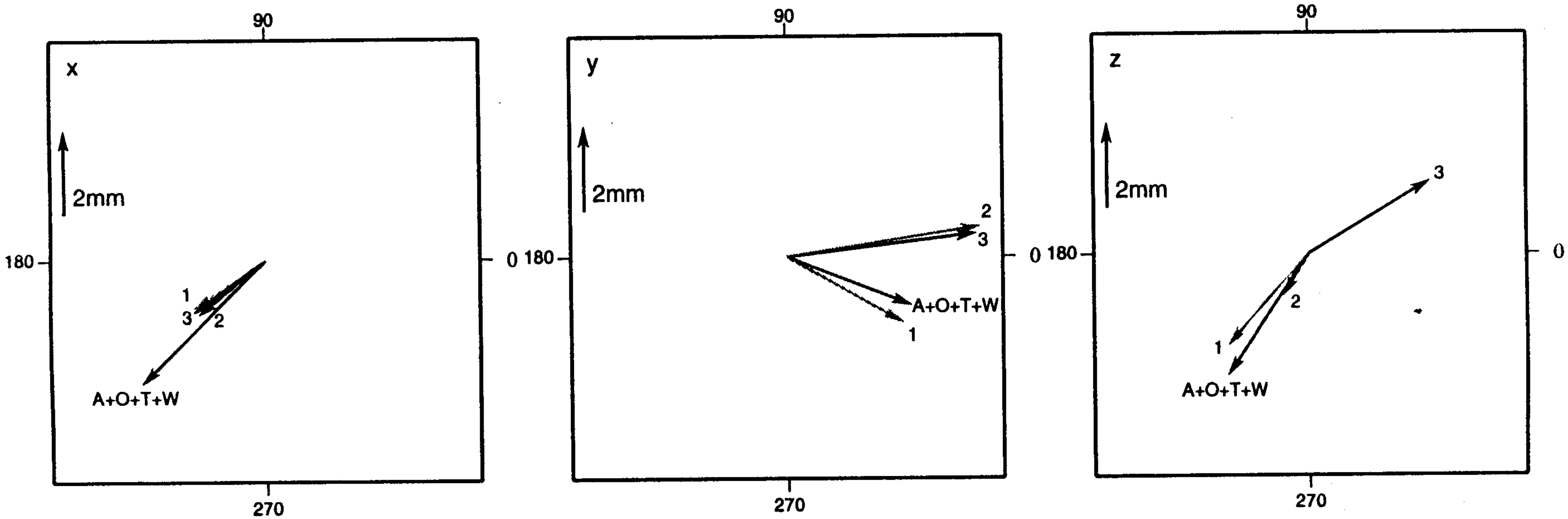

Figure 2: Comparison of the observed and inferred annual geocenter variations.
The notations of A, O, T, W and the phase convention are the same as Figure 1.
The notations of satellite solutions are: 1 LAGEOS I and II combination [Eanes et al., 1998],
2 TOPEX SLR solution [Cheng, 1998], 3 GPS solution scaled by 0.5 [Zhu et al., 1998].

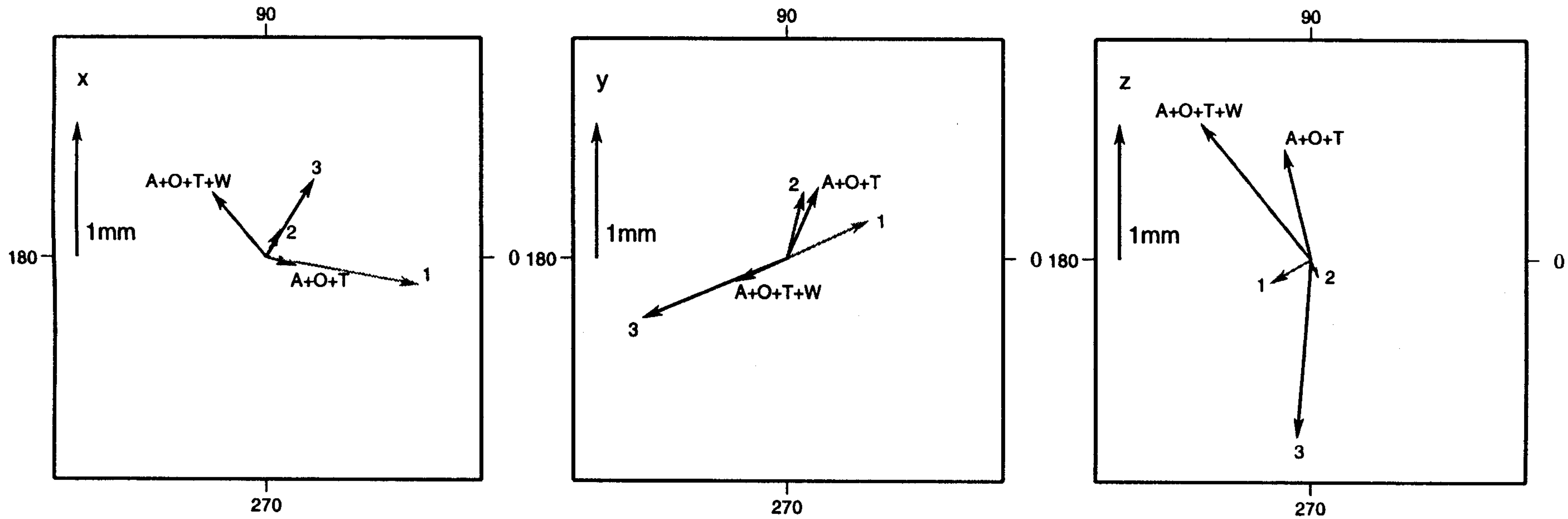

Figure 3: Comparison of the observed and inferred sami-annual geocenter variations.
The notations are the same as Figure 2.

et al. [1998] is within 12 degrees of the modeled solution. For the annual z component, the SLR solutions agree in phase with the modeled solution, the solution of *Eanes et al.* [1998] also has good agreement in amplitude with the modeled solution. The GPS solutions are roughly 155^0 out of phase and a factor of two larger in amplitude with the predicted solution. The agreement of the semiannual components are not as good as the annual components; in particular, we note that the semiannual ground water component degrades the agreement with the model predicted results. We found the similar phenomenon in the comparison between the satellite derived semiannual C_{even} with the model predicted results; adding the ground water contribution degrades the agreement with the model predicted results [*Dong at al.*, 1996]. Such a phenomenon could stem from either the errors in the satellite orbital forcing model, the ground water series or some missing contributions to the semiannual geocenter variations.

3. CONCLUSIONS

Determination of the geocenter variations due to surface mass load from various geophysical sources places constraints on the variations of the origin of terrestrial reference frame and provides a range of the geocenter variation spectrum for space-geodesy. The observed geocenter variations are the lumped sum of multiple contributors. Our results suggest that on the time scale from 30 days to 10 years the primary variability of geocenter variations from atmosphere, ocean and surface ground water occurs on seasonal time scales, which is within 1 cm level. Satellite derived solutions of the seasonal geocenter variations demonstrate good agreement with our model predicted geocenter variations, in particular for the annual components. Such an agreement is encouraging but not yet conclusive. However, at the current stage, the quantitative comparison between satellite derived and the geophysical model predicted geocenter variations is feasible; refined results are expected in the future.

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